(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 January 2005 (27.01.2005)

PCT

(10) International Publication Number
WO 2005/008583 A3

(51) International Patent Classification[7]: G06T 7/20, 11/00

(21) International Application Number: PCT/IL2004/000632

(22) International Filing Date: 14 July 2004 (14.07.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/488,382 21 July 2003 (21.07.2003) US

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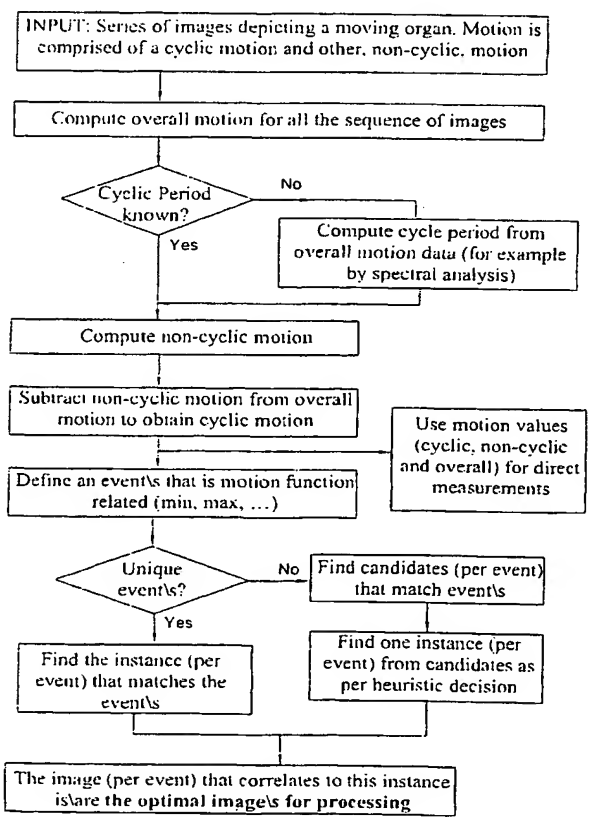
(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM,

[Continued on next page]

(54) Title: METHOD AND SYSTEM FOR IDENTIFYING AN OPTIMAL IMAGE WITHIN A SERIES OF IMAGES THAT DEPICT A MOVING ORGAN



(57) Abstract: A method and system for quantifying a cyclic motion within a series of images depicting a moving object subject to composite motion containing a cyclic component and a non-cyclic component of lower frequency than the cyclic component. Composite motion is computed. The non-cyclic component is computed as the integral of motion over a motion cycle. The non-cyclic component is subtracted from the composite motion so as to obtain the cyclic component.

WO 2005/008583 A3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL2004/000632

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06T7/20 G06T11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G06T G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX, IBM-TDB, BIOSIS, EMBASE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 885 594 A (MEDINOL LTD) 23 December 1998 (1998-12-23)	1,2, 5-10,12, 13,16-23
A	abstract page 2, line 42 - line 50 page 4, line 20 - page 5, line 23 page 7, line 30 - line 45 page 10, line 38 - line 44 page 13, line 22 - page 15, line 14 figures 2,9 -----	3,4,11, 14,15

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 September 2004	31. 01. 2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Engels, A

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-23

   processing a series of images depicting a moving object subject to composite motion for extracting a cyclic motion component;

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2. claims: 24-28

   analysis of a graphical representation of a cyclic motion for identifying those images in a series of images that depict an event associated with cyclic motion of a moving object;

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IL2004/000632

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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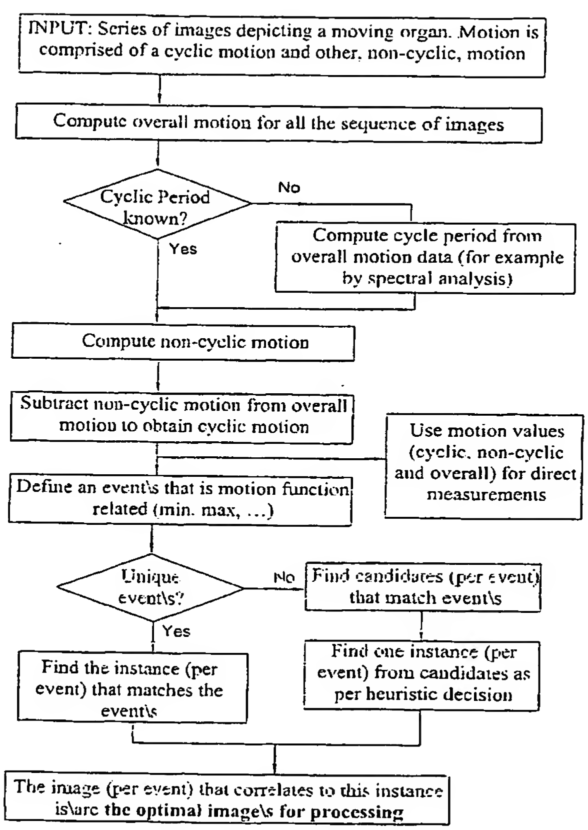

(57) **Abstract:** A method and system for quantifying a cyclic motion within a series of images depicting a moving object subject to composite motion containing a cyclic component and a non-cyclic component of lower frequency than the cyclic component. Composite motion is computed as well as the non-cyclic component as the integral of motion over a motion cycle. The non-cyclic component is subtracted from the composite motion so as to obtain the cyclic component.

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Method and system for identifying optimal image within a series of images that depict a moving organ

FIELD OF THE INVENTION

This invention relates to medical image processing devices.

BACKGROUND OF THE INVENTION

Medical imaging devices are often used to image moving organs. Cardiac image processing devices, in particular, are always used to image moving organs, either the heart (via ultrasound imaging for example), or the coronaries (via angiography for example). Many of these imaging processing devices are used to quantify the motion either as an indication by itself or as part of an image-processing algorithm.

An image processing device for Left Ventricle Analysis is used to evaluate Ejection Fraction, which is the percentage of the blood pumped out during each heartbeat. Left Ventricle Analysis involves computing the Left Ventricle volume from an angiogram (taken from a cine-angio sequence of images). The Left Ventricle volume is computed once for the heart in its systolic phase and once for the heart in its diastolic phase. Ejection Fraction is estimated from the ratio of these volumes. Identifying the systolic and diastolic images is part of the LVA procedure.

Myocardium thickness and Heart Wall Motion are evaluated from Ultrasound Images to indicate heart failure conditions. Both procedures, again, involve the identification of systolic and diastolic instances. Furthermore, quantifying the object's motion could be directly used for Wall Motion evaluation.

Intra-Vascular Ultrasound (IVUS) is a method of evaluating and analyzing coronary defects by means of inserting an intra-vascular ultrasound device and imaging the vessel. IVUS measurements include measurements of the luminal vessel area. Estimation of the luminal area very much depends on the heart phase and results vary for different images depicting different stages within the cardiac cycle. Again, it is useful to identify the diastolic - or the minimal movement instance - in order to perform measurements on the optimal image.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a method and system for imaging moving organs and to quantify the organ movements.

The present invention provides several methods and systems that relate to the evaluation of an organ motion.

According to the invention, there is provided a method for quantifying a cyclic motion within a series of images depicting a moving object subject to composite motion containing a cyclic component and a non-cyclic component of lower frequency than the cyclic component, the method comprising:

(a) computing the composite motion;

(b) computing the non-cyclic component as the integral of motion over a motion cycle; and

(c) subtracting the non-cyclic component from the composite motion so as to obtain the cyclic component.

The invention provides a novel method of evaluating the cyclic motion of an organ from a series of images of any source and provides implementations of such a method that decrease or eliminate motion artifacts. Specifically, we present a novel method and system for selecting optimal images for the process of 3D reconstruction of the coronaries. We further provide a method and system for replacing the need for ECG Gating by an analysis of the heart movement.

A method for estimating the motion of an organ of a series of images comprises the following operations. A medical imaging device acquires a series of images presenting an organ that is in motion. The motion is either of the organ changing shape (eventually, in a cyclic manner, regaining its original shape) or additionally of the organ changing location within the image (in angiography, for example, it is very common to move the patient's bed while imaging; as a result shifting the coronaries' location within the image). If a non-cyclic component is superimposed on the cyclic motion, the series of images are analyzed to separate the cyclic motion from the non-cyclic motion. Once these two types of motion are separated, the cyclic motion can be quantified. The quantified motion can now be used for direct measurements or can be investigated to identify different events within the motion cycle. In some implementations, this investigation will point to an image that is optimal in the sense that it represents minimal motion and thus yields

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

General principles

The invention will be described with particular reference to the determination of an optimal image within a series of images depicting heart motion possibly containing "noise" caused, for example, by shifting of the operating table on which a patient is disposed. Before doing so, some general algorithms will first be described.

Fig. 2 is a flow chart showing the principal operations carried out by a method according to the invention for identifying an optimal image from a series of images that depict a moving object.

Fig. 3 is a flow chart showing a preferred embodiment of such a method for identifying optimal image from a series of coronary cine-angiography images; this image being the input for a three-dimensional reconstruction of a the coronaries.

A series of images is received as input to from any imaging source. These images depict a moving organ subjected to two types of motions. The first is a cyclic motion of the object itself, meaning that, within a certain time frame, the object restores its original shape and position. The second is the motion of the object within the scene (image), meaning that the object changes position due to change in the imaging position. In the preferred embodiment of this method shown in Fig. 3, the images are a series of coronary angiographic images, obtained during a catheterization procedure. The cyclic motion is the heartbeat and the second motion could be, for example, movement of the C-ARM table, causing a shift of the imaged coronary vessels in the image.

First, the overall motion is computed for all sequence of images, using any method, for example optical flow or phase correlation.

If the cyclic period is unknown, then the cycle period is computed from the overall motion data. One method of doing so is by spectral analysis. The non-cyclic motion is computed, using overall motion and known or computed cycle period. A preferred embodiment of a known cycle period is the period of a cardiac cycle extracted from analysis of the ECG signal.

The non-cyclic motion is subtracted from the overall motion to obtain the cyclic motion. In the preferred embodiment shown in Fig. 3, the heartbeat motion is obtained by subtracting the non-cyclic motion (mainly attributed to movement of the patient's bed) from the overall motion.

this sequence are attributed to the organ's cyclic motion, but are also attributed to other factors.

If only cyclic motion is present, the first and the last images in this sequence must be identical, $IM_1=IM_{m+1}$.

Difference between images representing composite motion can be computed, as known in the art, by, for example, optical flow or by applying phase correlation computation to pairs of successive images IM_i and IM_{i+1}, $i\in\{1..m\}$. The result of this computation (for example the result of phase correlation) is described dX_i ,dY_i and ρ_i, where dX_i and dY_i are the shift between images (assuming a substantial part of the same pattern is present in both images) in X and Y axes respectively and ρ_i is the correlation grade. ρ_i may be used to enhance the further described algorithms.

Let us define and compute the motion integration as:

$$\begin{bmatrix} X_1 \\ Y_1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} X_{i+1} \\ Y_{i+1} \end{bmatrix} = \begin{bmatrix} X_i \\ Y_i \end{bmatrix} + \begin{bmatrix} dX_i \\ dY_i \end{bmatrix}$$

meaning that in the first image, the motion integral is equal to zero. The motion integral for image i+1 is equal to the motion integral for image *i* plus shift between images *i* and *i+1*, as computed by the phase correlation.

It is mathematically understandable that the integration of a cyclic motion, from image IM_1 to IM_{m+1}, is zero – if an object starts and ends in the same position, then the integration of the object movements (on X and Y axis) is zero (as shown in Fig. 1). Thus, if only cyclic motion is present, $(X_{m+1},Y_{m+1})=(X_1,Y_1)=(0,0)$.

Let (X_{NC},Y_{NC}) be the integral of the non-cyclic motion,

$(X_{NC},Y_{NC}) = (X_{m+1},Y_{m+1})$,

This means that, given that the integral of cyclic motion is 0, (X_{m+1},Y_{m+1}) represent the residual motion that is attributed to non-cyclic movement.

Assuming non-cyclic motion is consistent, or at the least that its frequency is lower than the cyclic motion frequency, we can subtract this motion from the overall motion:

$$(X_i^*,Y_i^*)=(X_i,Y_i)-(X_{NC},Y_{NC})*(i-1)/m, \qquad i=1,2,\ldots,m+1.$$

$D_{LM,E} = \max \{D_{i,E}\}$ for all $i=1..m+1$.

We can relieve the requirement for knowing in advance an approximation for the least motion image by means of direct computation. If indeed the least motion instance is not unique, we can use heuristic criteria for distinction. For example, within a sequence of angiograms, depicting a cardiac cycle, it is easy to distinguish between the end-systole instance and the end-diastole instance, both representing least motion, since the end-diastole instance is identified by presenting the coronaries in maximal spreading, while the end-systole instance is identified by presenting the coronaries in minimal spreading.

Preferred Embodiment.

We suggest a preferred embodiment for an application of three-dimensional reconstruction of coronary vessels from a procedure of conventional angiography. In order to reconstruct a three-dimensional image of the arteries, it is necessary to obtain at least two two-dimensional images of the arteries in the same phase of the heartbeat, for example at end-diastole. Therefore, image acquisition is usually synchronized to an ECG signal. This procedure involves simultaneous recordings of the video signal from the X-ray camera and the patient's ECG signal. We present here a novel method for identifying the end-diastole instance, equivalent to ECG-gating, without relying solely, if at all, on the ECG signal.

Let IM_1, IM_2... IM_n be n images of a catheterization-acquired run.

Let m be the number of frames per cardiac cycle, either known in advance or computed as detailed in the above-described method for estimating the organ's motion.

Let IM_k be the approximate location of end-diastolic frame within the cycle, either known in advance or heuristically identified as detailed in the above-described method for obtaining the least motion image.

$IM_{k-m/2}$, $IM_{k-m/2+1}$, $IM_{k-m/2+1}$ ... $IM_{k-m/2+m}$ form a full cardiac cycle (for the sake of simplicity, let us presume that m is an even number). Differences between frames in this sequence are attributed to heart motion, but are also attributed to bed motion, iodine propagation and several other reasons. If only heart motion were present, the first and the

Let:

$$D_{i,j} = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}$$

We can determine the end-systole point *S*, which is the one most distant from the approximated end-diastole point, meaning:

$$D_{S,m/2+1} = \max \{D_{i,m/2+1}\}$$

Minimum motion point – end-diastole, *ED* - is determined as most distant from systole point:

$$D_{S,ED} = \max \{D_{S,J}\}:$$

Selecting the IM_{ED} image per sequence of cine-angio images for the process of three-dimensional reconstruction will provide the optimal result, in terms of accuracy and precision, for the reconstruction and for vessel analysis.

In the method claims that follow, alphabetic characters and Roman numerals used to designate claim steps are provided for convenience only and do not imply any particular order of performing the steps.

It will also be understood that the system according to the invention may be a suitably programmed computer. Likewise, the invention contemplates a computer program being readable by a computer for executing the method of the invention. The invention further contemplates a machine-readable memory tangibly embodying a program of instructions executable by the machine for executing the method of the invention.

11. The method according to claim 10, wherein the selected image is closest to a predetermined approximation.

12. The method according to claim 10 or 11, wherein the event is least motion.

13. The method according to claim 12, for selecting angiographic images to participate in three-dimensional reconstruction of coronary vessels.

14. The method according to claim 13, including deriving cycle period and approximation for least-motion image from an analysis of an ECG signal.

15. The method according to claim 13 or 14, including distinguishing the end-diastole instance from the end-systole instance by the state of coronary vessel – maximal spreading versus minimal spreading, respectively.

16. The method according to any one of claims 5 to 15 when used for selecting optimal image or images for QCA analysis.

17. The method according to any one of claims 5 to 15 when used for selecting optimal image or images for IVUS analysis.

18. The method according to any one of claims 5 to 15 when used for selecting optimal image or images for LVA analysis.

19. The method according to any one of claims 5 to 15 when used for selecting optimal image or images for Wall Motion analysis.

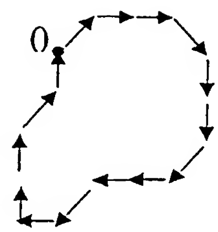
20. The method according to any one of claims 5 to 15 when used for CT reconstruction.

21. The method according to any one of claims 5 to 15 when used for MRI reconstruction.

22. The method according to any one of claims 5 to 15 when used for PET reconstruction.

23. A system for quantifying a cyclic motion within a series of images depicting a moving object subject to composite motion containing a cyclic component and a non-cyclic component of lower frequency than the cyclic component, the system comprising:

a composite motion unit computing the composite motion,



From point	To point	dX	dY	X	Y
0	1	1	1	1	1
1	2	1	0	2	1
2	3	1	0	3	1
3	4	1	-1	4	0
4	5	0	-1	4	-1
5	6	0	-1	4	-2
6	7	-1	-1	3	-3
7	8	-1	0	2	-3
8	9	-1	0	1	-3
9	10	-1	-1	0	-4
10	11	-1	0	-1	-4
11	12	0	1	-1	-3
12	13	0	1	-1	-2
13	14	1	1	0	-1
14	0	0	1	0	0

FIG. 1

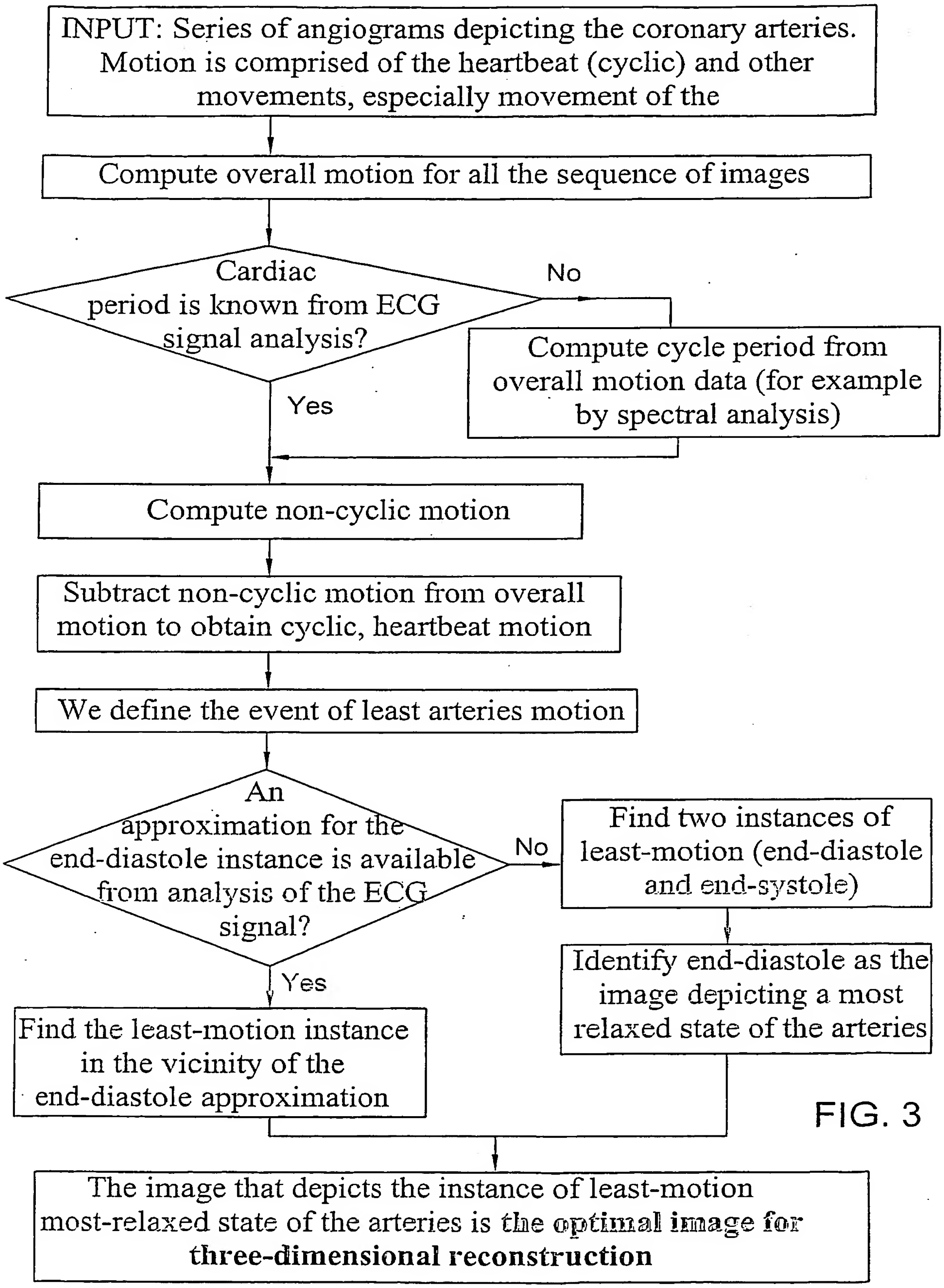

INPUT: Series of angiograms depicting the coronary arteries. Motion is comprised of the heartbeat (cyclic) and other movements, especially movement of the
Compute overall motion for all the sequence of images
Cardiac period is known from ECG signal analysis?
No
Compute cycle period from overall motion data (for example by spectral analysis)
Yes
Compute non-cyclic motion
Subtract non-cyclic motion from overall motion to obtain cyclic, heartbeat motion
We define the event of least arteries motion
An approximation for the end-diastole instance is available from analysis of the ECG signal?
No
Find two instances of least-motion (end-diastole and end-systole)
Identify end-diastole as the image depicting a most relaxed state of the arteries
Yes
Find the least-motion instance in the vicinity of the end-diastole approximation
The image that depicts the instance of least-motion most-relaxed state of the arteries is the optimal image for three-dimensional reconstruction

FIG. 3